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Sir:

Transmitted herewith for filing under 37 C.F.R. §1.53(b) is the patent application of:
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For: ION IMPLANTATION APPARATUS AND ION IMPLANTATION METHOD

XX   Specification (24 pages)

XX   _3_ sheets of drawings

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Respectfully submitted,

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ION IMPLANTATION APPARATUS AND ION IMPLANTATION METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to an ion implantation apparatus and an ion implantation method, both of which are necessary to implant an ion beam from an ion source into a wafer.

2. Description of the Related Art:

Generally, an ion implantation apparatus of this kind has an ion source, an acceleration and extraction electrode section, a mass analysis unit, a mass analysis slit, an acceleration/deceleration unit, a wafer processing chamber, and the like, all of which are disposed along a beam transportation path.   Such an ion implantation apparatus is used for implanting ions into a wafer, such as semiconductor wafer (hereafter, referred to merely as wafer).

Recently, a semiconductor device trends to increase its density and raise its degree of integration.   In order to realize such a high integrated semiconductor device, a technique is required for forming a shallow junction within the wafer.   Formation of such a shallow junction brings about necessity of an ion implantation apparatus which is capable of implanting an ion into the wafer with very low energy (less than 5 KeV, preferably below 1 KeV).

On implanting ions with very low energy ions, a method is conventionally adopted to obtain a sufficient beam electric current.   In this method, initially an ion beam is extracted with higher energy than desired. Then, the energy of the beam is decreased by decelerating the beam by the use of a deceleration electrode (will be simply referred to as decel) adjacent to

the wafer after low mass is analyzed.

SUMMARY OF THE INVENTION

According to inventors' experimental studies, it has been found out that ions with undesirable energy are implanted into the wafer and give rise to serious energy contamination, when the ions are implanted into the wafer with very low energy with the conventional method.   In addition, it has been also found out that such a contaminant ion reaches to a deeper position of the wafer than desired.

For such reasons, practical use might have not been realized yet about an ion implantation apparatus which is suitable for forming the shallow junction.

It is an object of the invention to realize an ion implantation apparatus which is suitable for forming a shallow junction.

It is another object of the invention to provide an ion implantation apparatus of the type described, which is capable of reducing an occurrence of an energy contamination.

It is still another object of the invention to provide an ion implantation method which is capable of implanting very low energy ions into a wafer, with a contamination reduced.

An ion implantation apparatus to which the present invention is applicable which comprises an ion source, an extraction electrode section, a mass analysis unit, a mass analysis slit and a wafer processing chamber.   By means of an embodiment of the invention, the ion implantation apparatus is constituted such that an ion implantation is controlled on the basis of a relationship between a beam transportation efficiency of an ion beam and an energy contamination in a wafer, and, as a result, the energy contamination in the wafer can be reduced.

Further, an ion implantation apparatus with another embodiment of the invention comprises a deceleration device within a beam line of the ion beam to

decelerate the ion beam. With this structure, the decelerated ion beam is controlled on the basis of the relationship between the beam transportation efficiency and the energy contamination. In this case, the deceleration capability is optimized on the basis of a measurement and consideration is made about the beam transportation efficiency between the deceleration electrode section and the wafer before an implant. Specifically, the energy contamination can be restricted to an amount less than an allowable amount on the basis of an inverse proportion relation between the beam transportation efficiency from the deceleration electrode section to the wafer and an amount of the energy contamination. The above energy transportation efficiency can be measured by Faraday cups one of which is located just after the deceleration electrode section and another of which is located just after the wafer. Such measurement of the energy transportation efficiency is carried out prior to the beginning of an ion implantation into the wafer.

The ion implantation apparatus according to yet another embodiment of the invention is constituted such that a measured value of the beam transportation efficiency is compared with a predetermined allowable lower limit value. As a result of comparison, the ion implantation is stopped when the measured value does not exceed the latter lower limit value. In addition, provision is made about a unit for tuning or adjusting both the ion source and a beam transportation system.

Further, when the measured value of the beam transportation efficiency is compared with the predetermined allowable lower limit value and the implantation is not started, an error message is displayed and both of the ion source and the beam transportation system may be automatically tuned again.

The above-mentioned tuning unit may have, as the mass analysis slit, a width selectable slit which is selectable in slit width on tuning the beam transportation system and which serves to adjust the beam. The width

selectable slit may be used in common to the deceleration electrode.

On the other hand, the tuning unit for tuning the beam transportation system may automatically switch a slit width of the mass analysis slit to a minimum width to adjust a beam axis and a coil electric current of a mass analysis magnet of the mass analysis unit.

As readily understood from the above, the invention measures the beam transportation efficiency prior to the beginning of implanting the ion to the wafer and determines a prescribed value which defines an allowable lower value in compliance with a desired allowable amount or quantity for the energy contamination or each recipe determined for each implantation.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view for explaining an ion implantation apparatus to which the invention can be applied;

Fig. 2 is a view showing an ion implantation apparatus according to one embodiment of the invention;

Fig. 3 is a diagram for showing a depth profile which appears on a deceleration implantation; and

Fig. 4 is a diagram showing a relationship between a beam transportation efficiency and an energy contamination.

DESCRIPTION OF THE PREFERRED EMBODIMENTS:

Referring to Fig. 1, description will be made about a schematic constitution of an ion implantation apparatus to which the invention is applicable, together with a principle of the invention.   First, the illustrated ion implantation apparatus comprises an ion source 15, an extraction and acceleration electrode section 17 (will be simply called an extraction electrode section hereinafter), a mass analysis unit or analyzer 16, a mass analysis slit 11, a wafer processing chamber 18, a Faraday flag or cup 12 and a Faraday disc or cup 14.   With this structure, a beam emitted from the ion source 15 is conducted through a

predetermine path or beam line to a wafer 13 located at an ion implantation position in the wafer processing chamber 18.

In case of the ion implantation apparatus shown in the drawing, the mass analysis slit 11 is used also as a deceleration unit (decel) for decelerating the beam. In the illustrated example, the Faraday flag 12 is disposed behind the mass analysis slit 11 while the Faraday disc 14 is disposed behind the wafer 13.

Incidentally, it is assumed that the invention is applied to an ion implantation apparatus which has no deceleration unit and which performs no deceleration. In this event also, the present invention is applicable to such an ion implantation apparatus without any problem.

Inasmuch as the mass analysis unit 16 has an analysis electromagnet, the desirable orbit of the ion beams extracted from the ion source 15 and the extraction electrode 17 is separated and selected according to the momentum determined by the ion species by the analysis electromagnet. In other words, each orbit is determined by each species of the ions. Thus, the ions are conducted in the form of an ion beam to the mass analysis slit 11 through an intermediate region 19.

While the ion beam passes through the intermediate region 19 extends through the analysis electromagnet to the mass analysis slit 11, the ions partially capture electrons and are neutralized by collisions with residual gas molecules and the like. Because the neutralized ions are not influenced by a deceleration electric field and are not decelerated, they pass through the mass analysis slit 11 and the wafer processing chamber 18 without any deceleration. As a result, it has been found out that the neutralized ions are implanted into the wafer with a high energy kept intact.

In addition, it has been confirmed that the neutralized ions are implanted as dopants in depths different from a desired ion and, as a result,

result in the energy contamination.

Especially, the neutralized ions implanted undesirably deeper than the plan are detrimental to formation of the shallow junction. More specifically, it has been found out that a shallow implantation can not be achieved when a large quantity or amount of energy contamination takes place within the wafer. This is because a depth of a junction is determined in dependency upon a deep junction formed by the contamination component, even if the ions are shallowly implanted with very low energy.

Since an allowable quantity or amount of the energy contamination depends on both a structure and a process of manufacturing a semiconductor device, although definite statement can not be made at present, it might be estimated that at its upper limit of the allowable amount may be in the order of less than several %.

Conventional thoughts are that an amount of the energy contamination depends on a distance from the analysis electromagnet to the mass analysis slit (namely, deceleration electrode section (decel)) 11 and a degree of vacuum in a zone corresponding to the distance.

However, according to experiments of the present inventors, it was found out that the amount or quantity of the energy contamination correlates with a beam transportation efficiency within the beam path located after the decel 11. This shows that the amount of the energy contamination largely depends on a travel distance of the beam after the deceleration, a degree of charge-up after the deceleration, a convergence-divergence action on the deceleration, tunings of the ion source and the analysis electromagnet, and the like.

Accordingly, this means that the amount of the energy contamination changes every time when the beam is tuned.

Heretofore, since nothing has been taken into consideration about a relation between the amount of the energy contamination on implantation and the transportation efficiency of the beam, it is actually impossible to estimate the energy contamination prior to the implantation. Therefore, adoption has been made about a method which actually measures and analyzes an actual depth profile for some days by arranging a monitor wafer for monitoring the contamination. However, this method is disadvantageous in that, since an ion implantation processing for a considerable number of wafers has been wasted by the above method before any inconvenience is actually found out. Thus, a loss of the wafer becomes large.

A principle of the invention is to reduce an amount of the energy contamination by previously measuring a correlation between the transportation efficiency of the beam after the decel. 11 and the energy contamination and by controlling the translation efficiency of the beam by the use of the measured correlation.

Referring to Fig.2, an ion implantation apparatus according to one embodiment of the invention comprises, like in Fig. 1, the ion source 15, the extraction electrode section 17, the mass analysis unit (electromagnet for analysis) 16, the mass analysis slit 11, and the wafer processing chamber 18. The illustrated intermediate region 19 has beam pipes 21 and 22 and the deceleration unit (decel) 11 for decelerating the beam. The decel 11 has a mass analysis slit 23 and a deceleration electrode 24. Similarly to Fig.1, the Faraday flag 12 is disposed just after the deceleration electrode 24 as a first measurement unit while the Faraday disc 14 is disposed as a second measurement unit after a wafer disc which mounts a batch of wafers 13. In the example shown in the drawing, the ion beam from the ion source 15 is conducted onto the wafer 13 in the wafer processing chamber 18 along a predetermined path, i.e., a predetermined beam line 30.

In the ion implantation apparatus shown in Fig.2, consideration is made about the case where a boron beam of n KeV is extracted from the ion source 15 and the boron beam is decelerated to one tenth (n/10 KeV) by the deceleration electrode 24 and implanted into the silicon wafer 13.

Referring to Fig.3, there is shown a profile representing a typical measured result of the wafer 13 by an SIMS in this case.

As apparent also from Fig.3, it is understood that the profile of the deceleration implantation can be separated into a component of n/10 KeV and a component of n KeV that is a contamination component. Further, it is understood that the contamination component partially overlaps with a target or desired dopant component at a shallow position of the wafer, and reaches to a position of the wafer deeper than that of the desired dopant component.

According to the invention, it has been found out that the energy contamination component is correlated with the beam transportation efficiency from the deceleration electrode section (decel.) 11 to the wafer. Taking this into consideration, such a profile measurement and component separation as mentioned above have been performed for cases where the beam transportation efficiencies were varied.

As a result, a correlation shown in Fig. 4 is obtained between the beam transportation efficiency and the energy contamination. In Fig.4, an abscissa and an ordinate represent a reciprocal of the beam transportation efficiency and a ratio (%) of the energy contamination, respectively. As apparent also from the drawing, it is understood that a very strong correlation exists between the reciprocal of the beam transportation efficiency and the ratio of the energy contamination. Although the reciprocal of the beam transportation efficiency is taken along the abscissa, it is needless to say that, in case where the beam transportation efficiency itself is adopted, there is a correlation of inverse proportion between the beam transportation efficiency and the energy

contamination.

Incidentally, in Fig.4, a result obtained by means of dividing a measured result of the flag Faraday 12 in Fig. 2 by a measured result of the disc Faraday 14 is shown as the beam transportation efficiency.

According to studies of the present inventors, it has been found out that the energy contamination component is mainly generated by the fact that the ions are neutralized in a linear zone from an outlet of the analyzer mainly formed by the mass analysis unit 16 to the decel electrode section 11 including the mass analysis slit.

Here, it is supposed that an electric current value of the ion beam passing through this zone is given by I_{i0} and the neutralized ion beam is represented by I_{N0}. When a neutralization rate is not so large, an amount of the neutralized beam is proportional to a quantity or amount of an original beam and is given by.

$$I_{N0} = \alpha I_{i0} \qquad (1)$$

A proportional coefficient α is representative of the neutralization rate and, in principle, depends on a length, a degree of vacuum, a residual gas kind, an ion species and an ion beam energy in the above zone.

Herein, it is assumed that the above-mentioned ion beam and neutralized ion beam are implanted into the wafer with electric current values I_{iD} and I_{ND}, respectively. In this case, a ratio C_{Ene} of the energy contamination is defined by a following formula.

$$C_{Ene} = I_{ND}/I_{iD} \qquad (2)$$

Let the transportation efficiency of the neutralized beam to the disc Faraday be represented by ε_N. A relation between the I_{N0} and the I_{ND} is expressed by a following formula.

$$I_{ND} = \varepsilon_N I_{N0} \qquad (3)$$

From these relations, the quantity of the energy contamination is expressed as follows.

$$C_{Ene} = \alpha\varepsilon_N \, (I_{i0}/I_{iD}) \qquad (4)$$

The I_{i0}/I_{iD} is a reciprocal of the beam transportation efficiency from the analyzer outlet to the wafer. Accordingly, if α and ε_N are constant, the ratio of the energy contamination is approximately in inverse proportion to the beam transportation efficiency. Further, the transportation efficiency ε_N of the neutralized beam is almost determined only by a width of the mass analysis slit and, as a result, becomes constant as long as the beam has low energy, and does not depend on a tuned beam. From the above facts, a proportionality, expressed by the formula (4), is assured between the energy contamination and the reciprocal of the beam transportation efficiency from the analyzer outlet to the wafer.

For measuring the beam, used is a beam electric current I_{iF} measured at the flag Faraday 12 which is a first Faraday cup just after the decel electrode section. If ε_{i1} is representative of the beam transportation efficiency (mostly determined by a passage rate of the resolving aperture) from the analyzer outlet to the Faraday flag 12, a relation between the beam electric current and the beam transportation efficiency is expressed by a following formula.

$$I_{iF} = \varepsilon_{i1}I_{i0} \qquad (5)$$

Further, a beam electric current I_{iD} implanted into the wafer is equal to a beam electric current measured at the Faraday disc 14 which may be called a second Faraday cup. Accordingly, an actually used formula becomes the formula which is different from the formula (4) and which is given by:

$$C_{Ene} = (\alpha\varepsilon_N/\varepsilon_{i1}) \, (I_{iF}/I_{iD}) \qquad (6)$$

In Equation (6), the term I_{iF}/I_{iD} is a reciprocal (I/ε_{i2}) of the beam transportation efficiency from the Faraday flag 12 to the Faraday disc 14.

In order to use the formula (6) for a contamination control, ε_{il} must seem to be constant.   However, different from ε_N, ε_{il} is affected by the tuning of the beam.   For example, if a focus is made blurred in order to cause the I_{iF}/I_{iD} to approach 100%, the beam allowed to pass through the resolving aperture is reduced, which results in lowering ε_{il}.   Thus, the contamination increases in comparison with the case where ε_{il} is constant.   Therefore, in order to actually use the formula (6), the tuning must be performed such that the beam is always focused on the resolving aperture of the mass analysis slit.   Since a design of the beam line is adapted such that the beam is focused on the resolving aperture.   If the tuning is performed normally, important is a time point when the tuning is deviated in order to increase the I_{iF}/I_{iD}.

In Fig.4, a proportional relation is illustrated between the C_{Ene} and the I_{iF}/I_{iD}.   In this case, it is understood that the energy contamination can be controlled in accordance with the formula (6).   In order to reduce an effective energy contamination to 1% or less, it suffices to say that the beam transportation efficiency is made 50% or more (the reciprocal of the beam transportation efficiency is made 2).

In the formula (6), C_{Ene} is representative of the energy contamination obtained by decomposing a depth profile of the decel implantation into the drift component (i.e., dopant component) and the contamination component and by taking an area ratio between them.   However, as shown in Fig.3, with very low energy, a shallow portion of the contamination component overlaps with the drift component as mentioned before but does not substantially becomes detrimental.

A substantial energy contamination used as an index of the energy contamination is defined by a value obtained by means of finding a depth in which a concentration of the drift component becomes X/cm^2 and by dividing a total number of the ions implanted more deeply by a total number of the ions

implanted more shallowly than the former ions.   Since the contamination by this definition necessarily becomes smaller than the C_{Ene} in the formula (6), if the C_{Ene} becomes less than 1%, also the substantial contamination necessarily becomes less than 1%.   That is, a control by the formula (6) is effective also for the substantial energy contamination.   Also a relation between the substantial energy contamination and the beam transportation efficiency approaches a proportional relation equal to the formula (6) (asymptotically approaches the formula (6)).

Accordingly, it is understood that, in order to suppress the energy contamination lower than the target value (1% as an example), it suffices if the beam transportation efficiency from the deceleration electrode section 11 to the wafer 13 is made larger than a correlation value (50% as an example) of the beam transportation efficiency corresponding to the energy contamination target value.   To the contrary, when the beam transportation efficiency does not exceed the correlation value of the beam transportation efficiency corresponding to the energy contamination target value, it is possible to cause the energy contamination exceeding an allowable amount not to enter, by applying an implantation interlock.

Accordingly, if the beam transportation efficiency is made larger than a certain correlation value (50% as an example), a component proportion of the desired beam increases and a component proportion of the neutral beam in the beam can be lowered, so that the energy contamination can be reduced to the target value (1% as an example).

As mentioned before, the ion implantation apparatus comprises the ion source 15, the extraction electrode 17, the mass analysis unit 16, the mass analysis slit 23, the wafer processing chamber 18, and the like.   Under the circumstances, the component proportion of the neutral beam in the beam measured at an intermediate convergent point or at a position before or after

the mass analysis slit 23 must be controlled so that it becomes below a constant proportion. In this event, a component proportion of the neutral beam in the beam must be adjusted to a value which corresponds to the target value of the beam transportation efficiency when the beam transportation efficiency is 100% or even when the beam transportation efficiency is made a certain correlation value.

Description will be made about the above-mentioned fact in detail with reference to Fig. 2. The beam transportation efficiency is measured, within the intermediate chamber 19 having the beam pipes 21 and 22, by placing the Faraday flag 12 (the first measurement unit) just after the deceleration electrode section 11 composed of the mass analysis slit 23 and the deceleration electrode 24. In addition, the Faraday disc 14 (the second measurement unit) is placed just after the wafer disc. If electric current values measured by the respective Faraday cups 12 and 14 are compared with each other, the beam transportation efficiency is calculated from the electric current values. By moving the wafer disc in an up-and-down direction in Fig.2, a scanning operation can be performed and, by this operation, the wafer disc is preliminarily moved to a position displaced from the beam line 30.

Under this state, since the ion beam is not implanted into the wafer 13, the measurement is performed by the first and second measurement units. Thus, it is judged prior to the ion implantation whether or not a measured value reaches the specified value (default value is 50%, as an example) which may be an allowable lower limit value. If it does not reach the specified value, the implantation is stopped. The specified value can be set according to a recipe in compliance with an allowable amount with respect to the target energy contamination. Incidentally, as to the transportation efficiency, the example has used the Faraday cups. However, any other system can be used to measure the beam electric current and may be, for example, a profile line type

sensor, a system directly detecting the electric current from a wafer surface disc.

By adjusting the ion source 15 and the analyzer 16 again, the beam transportation efficiency is improved to some extent.   Therefore, simultaneously with an implantation stoppage, a message demanding to adjust the ion source 15 and the analyzer 16 again may be displayed on an operator interface screen.

The deceleration electrode 24 applies a deceleration action to the ion beam, and it may be separately provided behind or in front of the mass analysis slit 23 and may be used also as the mass analysis slit 23.   The mass analysis slit 23 for the ions is adapted such that a slit width of opening is automatically and stepwise changed in compliance with a mass resolving power necessary for each ion kind.

The mass analysis slit 23 for the ions automatically reduces the slit width to a minimum only when a beam center axis is aligned by oscillating a coil electric current of the analyzer 16.

A measurement of the ion transportation efficiency and a judgment about whether or not the ion implantation is carried out are automatically implemented by a dose control program of the apparatus.   This program measures the beam transportation efficiency with reference to a lower limit value of a beam transportation efficiency determined by the recipe and judges whether or not the beam transportation efficiency exceeds the lower limit value. In the case where the efficiency is insufficient, the ion implantation is not started, and an error message may be displayed on a monitor screen.

In this case, it is also possible to automatically perform tunings of the ion source 15 and the analyzer 16 by being linked with a program of auto-tuning.

In a deceleration implantation, the implantation is performed through the slit of a maximum width, but this system has a problem that a center axis of the beam is difficult to be adjusted. However, by means of automatically reducing the slit width to the minimum only when the beam center axis is aligned by oscillating the coil electric current of the analyzer, it is possible to increase the beam transportation efficiency while the center axis of the beam is being adjusted.

As mentioned above, the method according to the invention comprises the steps of adjusting the energy contamination in the ion implantation apparatus comprising the ion source, the extraction electrode, the mass analysis unit, the mass analysis slit, the wafer processing chamber, and the like. Concretely, the adjustment of the energy contamination is performed by controlling the ion implantation on the basis of a relation between the beam transportation efficiency of the ion beam and the energy contamination of the wafer.

Further, it may be constituted such that, by providing the deceleration unit in the beam line of the ion beam, the implantation is controlled at a time of deceleration implantation using the deceleration unit on the basis of the relation between beam transportation efficiency and the energy contamination. The deceleration unit is composed of the deceleration electrode section and can be constituted so that the energy contamination does not exceed an allowable quantity, on the basis of an inverse proportion relation between the beam transportation efficiency from the deceleration electrode section to the wafer and the amount of the energy contamination.

The beam transportation efficiency is measured before the implantation into the wafer is started, by providing the Faraday cups placed just after the deceleration electrode section and just after the wafer. Further, a measured value of the beam transportation efficiency is compared with a predetermined

allowable lower limit value, and the implantation is not started in case where the former value does not exceed the latter value.

It is also possible to tune the beam transportation efficiency by utilizing the ion source and a beam transportation system. Thus, the measured value of the beam transportation efficiency is compared with the predetermined allowable lower limit value and the implantation is stopped when the former value does not exceed the latter value. In this case, an error message may be displayed in case where the implantation is not started. In addition, the ion source and the beam transportation system may be automatically tuned again.

When tuning the beam transportation system, it is also possible to adjust the beam by making the mass analysis slit into a variable slit width system and, further, the mass analysis slit may be used also as the deceleration electrode.

When the beam transportation system is being tuned, an axis alignment of the beam may be performed by automatically switching to a minimum width mass analysis slit, and a coil electric current of the analyzer may be adjusted.

Incidentally, the first Faraday flag may be provided just before the mass analysis slit and just before or just after the mass analysis besides it is provided just after the deceleration electrode section. Also the second Faraday disc may be provided at the same position as the wafer disc and at a position just before the wafer disc.

By placing the Faraday flag 12 (the first measurement unit) just after the deceleration electrode section 11 and placing the Faraday disc 14 (the second measurement unit) just after the wafer disc, the beam translation efficiency between both the measurement units is measured. If the electric current values measured by the respective Faraday cups are compared with each other, the beam transportation efficiency is calculated. This measurement is performed before the ions are implanted into the wafer, by displacing the wafer

disc to a position deviated from the beam line and, under this state, using the first and second measurement bodies.   It is judged whether or not a result of the measurement reaches the specified value (default is 50%, as an example) becoming the allowable lower limit value and, if it does not reach the specified value, the implantation is stopped.   The specified value can be set according to the recipe in compliance with the allowable quantity, with respect to the energy contamination, of an apparatus user.

By adjusting the ion source 15 and the analyzer 16 again, the beam transportation efficiency is improved in some extent.   Therefore, simultaneously with the implantation stoppage, the message demanding to adjust the ion source and the analyzer again is displayed on the operator interface screen.

The deceleration electrode 24 applies the deceleration action to the ion beam, and it may be separately provided behind or in front of the mass analysis slit 23 and may be used also as the mass analysis slit 23.   The mass analysis slit 23 for the ions is adapted such that the slit width of opening is automatically and stepwise changed in compliance with the mass resolving power necessary for each ion kind.

The mass analysis slit 23 for the ions automatically reduces the slit width to the minimum only when the beam center axis is aligned by oscillating the coil electric current of the analyzer.

According to the invention, it is possible to adjust the component proportion of the neutral beam in the beam at the intermediate convergent point of the beam or at a position before or after the mass analysis slit such that it becomes below a constant proportion and, by this, a maximum energy contamination quantity can be inferred.   Further, in the invention, if the transportation efficiency from the intermediate convergent point of the beam or from the position before or after the mass analysis slit to the wafer is measured,

an actual energy contamination quantity can be inferred, so that the energy contamination can be controlled. Furthermore, even in an apparatus not performing the deceleration, a reduction in throughput owing to a beam transportation efficiency reduction can be prevented.

Further, the energy contamination quantity can be monitored at the time of implantation.

Hitherto, it has been difficult to control the energy contamination, but it is possible to control it by the beam transportation efficiency, and it is also possible to raise the beam transportation efficiency while adjusting the center axis of the beam.

In the invention, since the contamination component implanted more deeply than the program can be reduced, a generation of a large quantity of energy contamination can be prevented. Accordingly, it is possible to avoid a disadvantage that a junction depth is determined by the contamination component, and it is possible to reduce the allowable quantity of the energy contamination below the target value.

By improving the beam transportation efficiency after the decel., it is possible to control the quantity of the energy contamination changing every time the tuning of the beam is performed, by means of utilizing the fact that the quantity of the energy contamination largely depends on a travel distance of the beam after the deceleration, a degree of the charge-up after the deceleration, a convergence-divergence action at the time of deceleration, tunings of the ion source and the analysis electromagnet, and the like.

WHAT IS CLAIMED IS:

1. An ion implantation apparatus for use in implanting an ion beam into a wafer by conducting the ion beam to the wafer along a predetermined path, the ion implantation apparatus comprising:

means for measuring, along the predetermined path, beam energy at a plurality of measurement positions different from each other;

means for obtaining a beam transportation efficiency between the measurement positions from the beam energy measured at the respective measurement positions; and

means for reducing energy contamination implanted in the wafer, by using a correlation between the energy contamination implanted into the wafer and the beam transportation efficiency.

2. An ion implantation apparatus as claimed in claim 1, the apparatus having an intermediate convergent point or a mass analysis slit for converging the beam within the predetermine path, wherein one of the measurement positions is determined at a front or rear position of the intermediate convergent point or the mass analysis slit, the apparatus being adjusted at the one of the measurement positions so that a rate of a neutral beam to the beam is not higher than a predetermined rate.

3. An ion implantation apparatus as claimed in claim 2, wherein the correlation is computed on the basis of a table which stores measurement data of a correlation between the beam transportation efficiency and the energy contamination in the wafer.

4. An ion implantation apparatus as claimed in claim 3, wherein the correlation is specified by an inverse proportion relation between the energy contamination and the beam transportation efficiency.

5. An ion implantation apparatus as claimed in claim 1, the apparatus comprising an ion source, an analyzer, an ion deceleration electrode, and a wafer processing chamber, wherein the measurement positions are determined at a rear position of the ion deceleration electrode and an ion implantation position of the wafer processing chamber;

the beam transportation efficiency being calculated from results measured at the respective measurement positions.

6. An ion implantation apparatus claimed in claim 5, wherein an amount of the energy contamination is determined with reference to a deceleration rate based on the ion deceleration electrode.

7. An ion implantation method for use in an ion implantation apparatus comprising an ion source, an extraction electrode, a mass analysis unit, a mass analysis slit, and a wafer processing chamber, comprising the steps of:

deciding a target value in a wafer related to an amount of energy contamination;

measuring a beam transportation efficiency of an ion beam; and adjusting the amount of the energy contamination in the wafer to a value not higher than the target value by the use of a correlation between the beam transportation efficiency and the energy contamination.

8. An ion implantation method as claimed in claim 7, further comprising the steps of:

measuring the ion transportation efficiency of the ion beam; and

judging whether or not ion implantation is to be judged with reference to the target value determined for the energy contamination.

9. A method of implanting ions into a wafer, comprising the steps of:

setting a beam transportation efficiency to a predetermined value to decrease a rate of a neutral beam to a beam and to thereby enhance a rate of a desired beam to the beam; and

reducing an energy contamination to a value lower than a target value.

10. An ion implantation apparatus comprising an ion source, an extraction electrode, a mass analysis unit, a mass analysis slit, and a wafer processing chamber, the apparatus having one of measurement points determined at an intermediate convergent point or at a front or rear position of the mass analysis slit and being controlled so that a rate of neutral beam to a beam becomes lower than a predetermined rate.

11. An ion implantation apparatus as claimed in claim 10, comprising a first Faraday cup that is located at a first position determined at a front or a rear position of either of intermediate convergent point and the mass analysis slit; a second Faraday cup that is located at a second position determined at a front or rear position of a wafer:

means for measuring beam electric currents at the first and the second positions to calculate a difference between the beam electric currents measured at the first and the second positions and to obtain a beam transportation efficiency with reference to the difference.

12. An ion implantation apparatus as claimed in claim 10, wherein a deceleration unit is provided within a beam path of ion beam, and an amount of ion implantation is controlled and adjusted on the basis of a relation between a beam transportation efficiency obtained by the use of the deceleration unit and an energy contamination.

13. An ion implantation apparatus as claimed in claim 12, wherein the deceleration unit is composed of a deceleration electrode section;

the apparatus being controlled so that the energy contamination does not exceed an allowable amount on the basis of an inverse proportion relation between a beam transportation efficiency from the deceleration electrode section to a wafer and the amount of the energy contamination.

14. An ion implantation apparatus as claimed in claim 13, comprising a first Faraday cup located just after the deceleration electrode section and a second Faraday cup located just after the wafer;

the beam translation efficiency before implantation into the wafer being measured by the use of the first and the second Faraday cups.

15. An ion implantation apparatus claimed in claims 11, wherein the implantation is not carried out by comparing a measured value of the beam transportation efficiency with a predetermined allowable lower limit value and by detecting that the former value does not exceed the latter value.

16. An ion implantation apparatus as claimed in claim 10, further comprising:

means for tuning the ion source and a beam transportation system.

17. An ion implantation apparatus as claimed in claim 10, further comprising:

means for comparing the measured value of the beam transportation efficiency with the predetermined allowable lower limit value;

means for stopping the implantation in the case where the measured value does not exceed the predetermined allowable lower limit value; and

means for displaying an error message in the case where the implantation is stopped so as to automatically tune the ion source and the beam transportation system again.

18. An ion implantation apparatus as claimed in claim 10, wherein the mass analysis slit is variable in a slit width which adjusts the beam on tuning the beam transportation system.

19. An ion implantation apparatus as claimed in claim 12, wherein the mass analysis slit is used also as a deceleration electrode.

20. An ion implantation apparatus as claimed in claim 10, wherein automatic switching is made to a mass analysis slit of a minimum width on

tuning a beam transportation system to adjust a beam axis and to adjust a coil electric current of an analyzer.

21. An ion implantation apparatus as claimed in claim 12, wherein the beam transportation efficiency is measured by a Faraday flag provided just after a deceleration electrode section and a Faraday disk provided just after a wafer.

22. An ion implantation apparatus as claimed in claim 10, wherein a beam transportation efficiency is measured before the beam starts to impinge to a wafer.

23. An ion implantation apparatus as claimed in claim 15, wherein a specified value which serves as the allowable lower limit value is set in compliance with an amount of desired allowable for the energy contamination or each implantation recipe.

24. An ion implantation apparatus comprising:

a table for storing measured results in necessary beam electric current values on the basis of an inverse proportion relation between a beam transportation efficiency in each ion species and an amount of an energy contamination; and

means for adjusting the energy contamination of ion implantation in the each necessary beam electric current value, by using a limit beam transportation efficiency value obtained on the basis of the table.

ABSTRACT OF THE DISCLOSURE

In an ion implantation apparatus, a reduction of an energy contamination is achieved when ions are implanted into a wafer with a low energy. A beam transportation efficiency between mutually different positions on a beam line correlates with the energy contamination of the wafer, and the beam transportation efficiency is adjusted so that the energy contamination becomes small. Since the beam transportation efficiency is obtained by measuring a beam electric current at each position, the beam transportation efficiency can be obtained before the ions are implanted into the wafer.
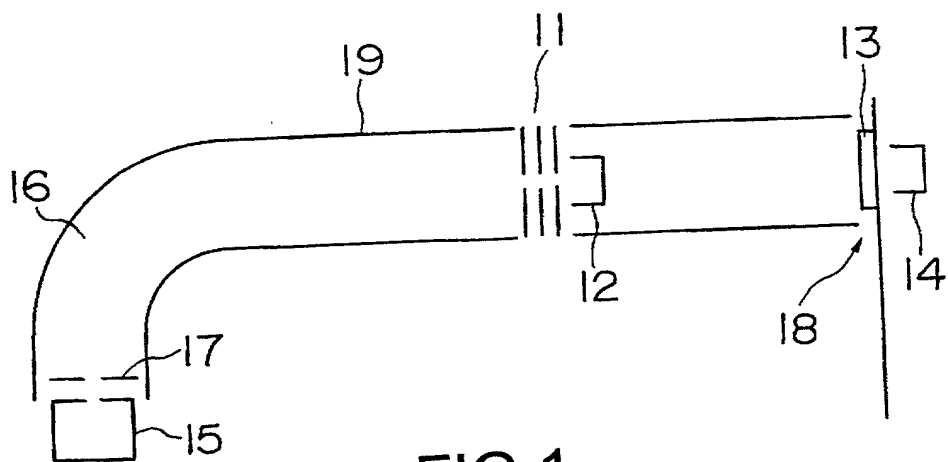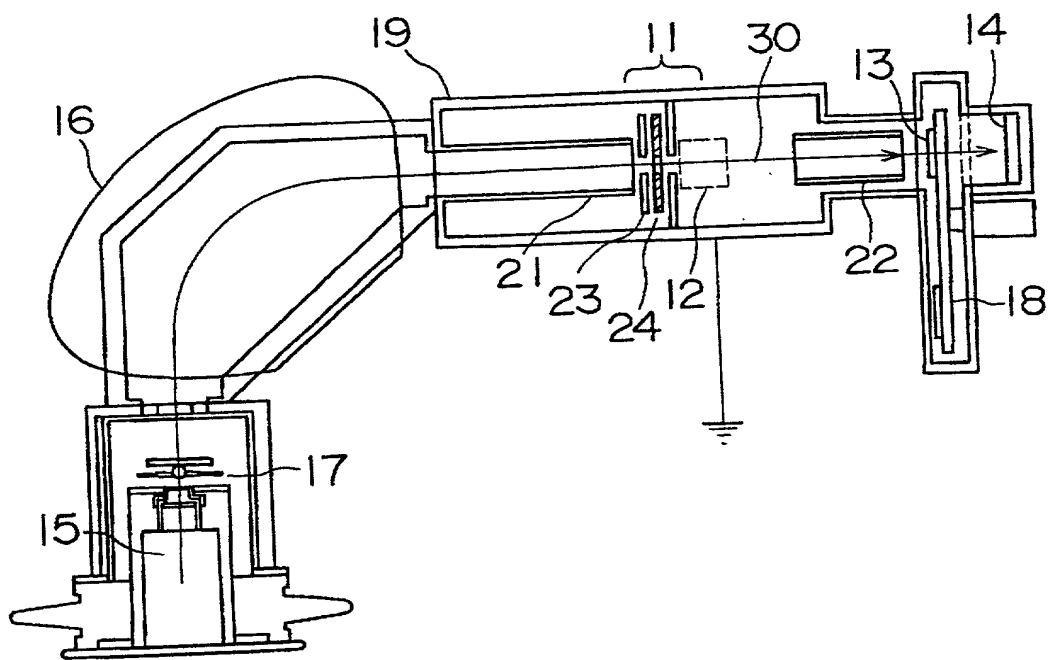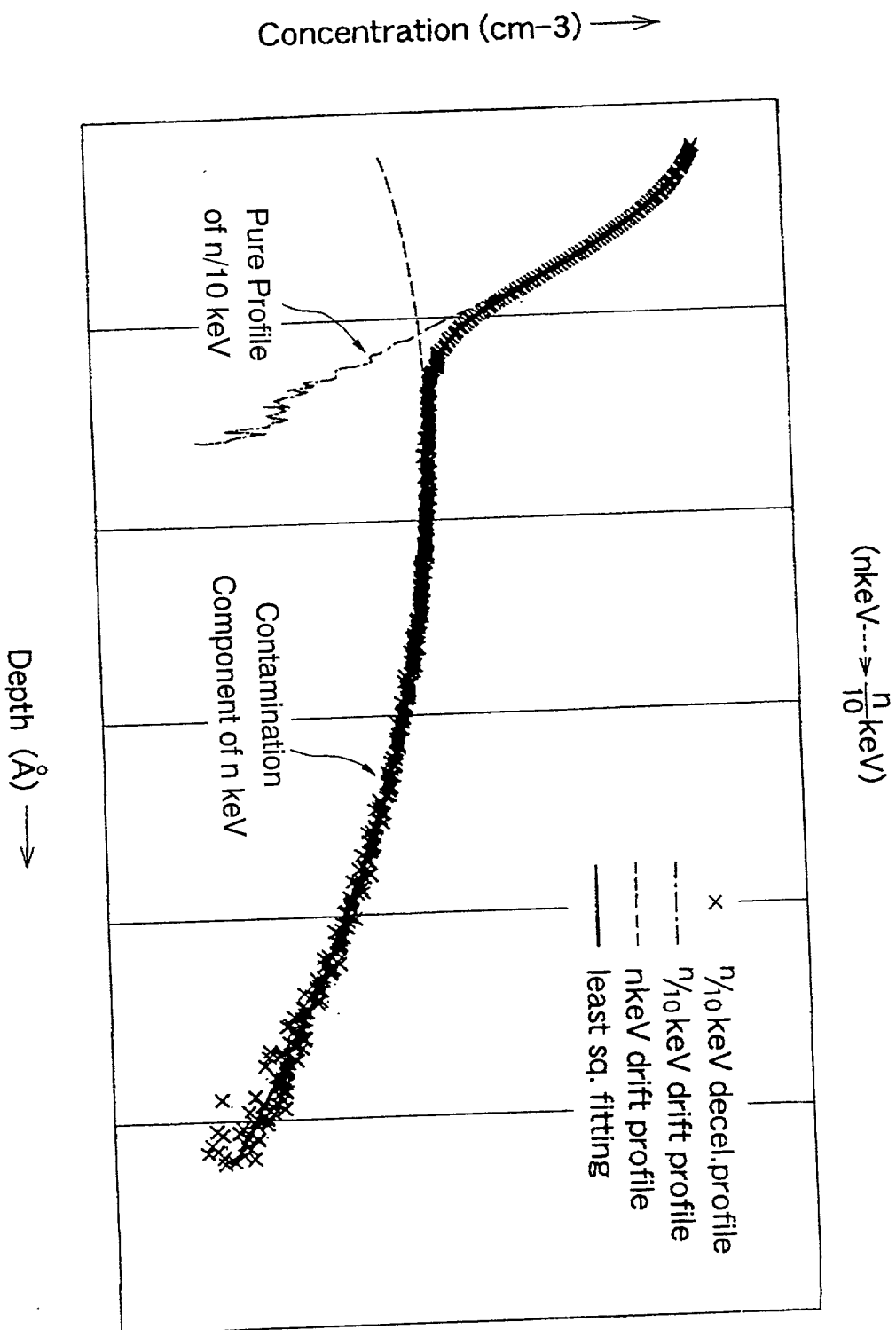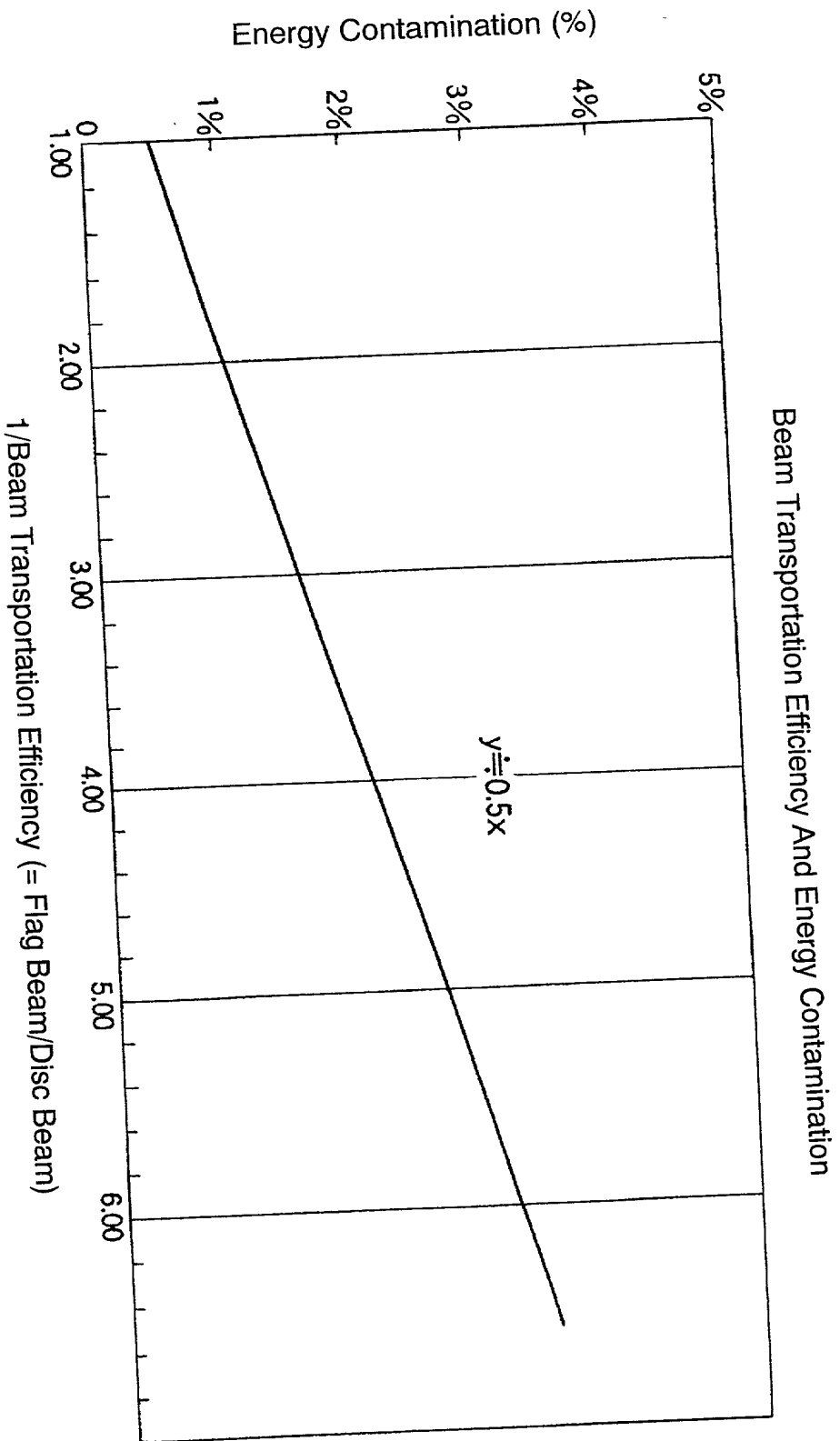
FIG.1

FIG.2

FIG.3

Concentration (cm-3) →

Depth (Å) →

$n/10$ keV ---→ $\frac{n}{10}$keV)

Pure Profile
of n/10 keV

Contamination
Component of n keV

× $n/10$keV decel.profile
—·—·— $n/10$keV drift profile
— — —   nkeV drift profile
————   least sq. fitting

Beam Transportation Efficiency And Energy Contamination

Energy Contamination (%)

1/Beam Transportation Efficiency (= Flag Beam/Disc Beam)

y≒0.5x

FIG.4

Docket No. _____

ARENT FOX KINTNER PLOTKIN & KAHN, PLLC
Nikaido, Marmelstein, Murray & Oram Intellectual Property Group

Declaration For U.S. Patent Application

As a below named inventor, I hereby declare that:
My residence, post office address and citizenship are as stated below my name.
I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled (Insert Title) __ION IMPLANTATION APPARATUS AND ION IMPLANTATION METHOD_____

the specification of which is attached hereto unless the following box is checked:

☐ was filed on _____ as PCT International Application
Number _____ and was amended on _____
and/or was filed on _____ as United States Application
Number _____ and was amended on _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above.
I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56.
I hereby claim foreign priority benefits under 35 U.S.C. §119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below any foreign application for patent or inventor's certificate or PCT International Application having a filing date before that of the application(s) for which priority is claimed:

(List prior foreign applications. See note A on back of this page)	216626/1999 (Number)	Japan (Country)	30 July 1999 (Day/Month/Year Filed)	Priority Claimed ☒ Yes ☐ No
	(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes ☐ No
	(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes ☐ No

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

(Application Number)   (Filing Date)

(Application Number)   (Filing Date)

(See Note B on back of this page)   ☐ See attached list for additional prior foreign or provisional applications.

I hereby claim the benefit under 35 U.S.C. §120 of any United States application(s) or §365(c) of any PCT International application(s) designating the United States of America listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior application(s) (U.S. or PCT) in the manner provided by the first paragraph of 35, U.S.C. §112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

| (List prior U.S. Applications or PCT International applications designating the U.S.) | (Application Serial No.) | (Filing Date) | (Status) (patented, pending, abandoned) |
| | (Application Serial No.) | (Filing Date) | (Status) (patented, pending, abandoned) |

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

(See Note C on back of this page)

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